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SUBLIMATING ICY PLANETESIMALS AS THE SOURCE OF NUCLEATION SEEDS FOR
GRAIN CONDENSATION IN CLASSICAL NOVAE

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ABSTRACT. The problem of grain nucleation during novae outbursts is a major obstacle to our understanding of dust formation in these systems. How nucleation seeds can form in the hostile post-outburst environment remains an unresolved matter. We suggest here that the material for seeding the condensation of ejecta outflow is stored in a primordial disk of icy planetesimals surrounding the system. Evidence is presented that the requisite number of nucleation seeds can be released by sublimation of the planetesimals during an outburst.

I. INTRODUCTION

The sources of the small dust grains observed by IRAS around Vega, β -Pic and numerous other old main sequence stars are believed to be extended shells or disks of cometary material (Harper et al., 1984; Weissman, 1984). The mass of material directly seen in these systems in the form of particle sizes $\leq 1 \mu\text{m}$ is $\geq 0.01 M_{\odot}$ (Gillett, 1986). Since the optical depth in these systems implies that collision time scales are less than their ages, there must be unseen parent bodies which repopulate the smaller sizes and significantly add to the total mass contained in these disks (Whitmire et al., 1988). Indeed the conventional viewpoint is that primordial disks of icy planetesimals will survive in transplanetary regions (Kuiper, 1951; Cameron, 1962). It has been argued that the Solar System contains such a disk from which short period comets originate (Fernandez, 1980; Matese and Whitmire, 1986; Duncan et al., 1988). The mass content out to 100 AU is estimated to be $\sim 1 M_{\oplus}$. It is to be emphasized that the cometary disk discussed here is distinct from the conventional isotropic inner (Hills, 1981) and outer Oort cloud.

Here we estimate the amount of dust that will be released from such a disk during a classical nova outburst. The significance of this source of dust to the grain condensation problem will then be described.

II. ANALYSIS

It has been shown (Ney, 1982) that the observed mass loss rate (volatiles and solids) for comets can be fit to the form

$$dM/dt = -kM^{2/3} \exp(-1552/T) \quad (1)$$

where T is the local blackbody temperature in kelvins. The Boltzmann factor is appropriate for the activation energy of water release from clathrates whereas the coefficient k depends on specific surface absorptivity and activity, being smaller for older comets like Encke (Ferrin and Gil, 1988). We assume that equation (1) is applicable to smaller icy planetesimals as well. When such objects are exposed for a time t to the emerging flux of a nova outburst of luminosity $L \approx L_{\text{Edd}} = 4 * 10^4 L_{\odot}$ then all planetesimals of initial mass $M_0 < M_c(t)$ will be completely sublimated. One finds

$$\begin{aligned} M_c(t) &= [(kt/3) \exp(-1552/T)]^3 \\ &= 3 * 10^8 \text{ g } (t/60\text{d})^3 \exp[-1.2(L_{\text{Edd}}/L)^{1/4} R^{1/2}(\text{AU})]. \end{aligned} \quad (2)$$

In evaluating equation (2) we have conservatively adopted the value of k appropriate to Encke, $k(\text{Encke}) = 3.7 * 10^{-4} \text{ g}^{1/3} \text{ s}^{-1}$.

Those planetesimals of initial mass $M_c(t) < M_0 < M_{\text{max}}$ will be partially sublimated. If the initial number density of these objects is represented by the power law M_0^{-b} then the fraction of the net mass content of these objects which is released is given by

$$\epsilon(t) = C_b (M_c(t)/M_{\text{max}})^{2-b} \quad (3)$$

where C_b is order(1) for $5/3 < b < 2$.

Therefore, 60 days subsequent to an outburst of $L = L_{\text{Edd}}$, planetesimals at a distance of 50 AU will have all of their volatiles sublimated and their dust released if their mass is $\leq 6 * 10^4 \text{ g}$. At this distance the blackbody temperature is $\approx 550\text{K}$ but the dust would be hotter if it radiated inefficiently. A cometary distribution with $b = 11/6$ (corresponding to a size power law of $7/2$) and $M_{\text{max}} = 10^2 \text{ g}$ would release a mass fraction $\epsilon(60\text{d}) = 0.004$. The planetesimals that do survive should be stirred due to outgassing (Katz, 1988), thus providing a mechanism for collisionally repopulating the size distribution for masses $< M_c$ in the intervening time between outbursts. In turn the disk should thicken somewhat.

III. DISCUSSION

Although correlations between outburst characteristics (speed class, energy output, system velocities) and dust characteristics (production onset, optical depth) do exist (Gallagher and Starrfield, 1978), there

are enough exceptions (eg. Gehrz et al., 1988) to preclude a clear understanding of how conventional ideas can predict the location where dust begins to form and how much dust will form.

Dust growth requires a nucleation seed (a cluster exceeding a critical size where condensation is more likely than evaporation) as well as outflow properties that are conducive to an increase in size. There is considerable controversy over whether classical nucleation theory (eg. Draine and Salpeter, 1977) is applicable (Draine, 1985; Donn and Nuth, 1985) but in any case the formation of seeds is as yet an unresolved problem. We suggest that the problem can be mitigated if icy planetesimals do indeed survive in the regions around 50-100 AU as argued in the Introduction.

If $10^{-3} M_{\odot}$ of material is released from planetesimals during an outburst and ten percent (Ney, 1982) is in the form of solids then $3 \times 10^{-10} M_{\odot}$ of dust grains will be deposited in the disk and subjected to the ablative and accelerative effects of the outflow. This amount of material is comparable to that estimated to exist surrounding the dust-poor slow nova PW Vulpeculae (Gehrz et al., 1988). If such a dust disk is formed in an outflow where condensation is kinetically favorable and the mean grain radius enlarged by a factor of ten, then an enhancement in the mass of dust to levels estimated to exist in dust-rich novae will occur. Some distinguishing features of this model from other models that invoke preexisting dust grains or nucleation seeds (see eg. Bode and Evans, 1980) are that prior to the eruption the preponderance of pre-ablated seeds were stored, since primordial times, inside icy planetesimals having a disklike distribution. Thus first time novae are equally likely to show IR excesses.

Finally, we emphasize that the nucleation seed distribution would be disklike in our model. Therefore, independent of the distribution of ejecta from the C-O white dwarf, the distribution of condensates should also be disklike rather than isotropic.

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